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Development of Wind Pair Databases at Kennedy Space Center, Vandenberg Air Force Base and Wallops Flight Facility

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Executive Summary

Space launch vehicle launch commit decisions include an assessment of the vehicle's response to upper level (UL) atmospheric winds during ascent, which is performed to determine the wind environment effects on the vehicle's controllability and structural integrity. These assessments are based on measurements obtained at specified times prior to the actual launch. However, the pre-launch measured winds may not represent the environment through which the vehicle will ascend. Statistical analysis of wind change over time periods of interest using historical data from the launch range can mitigate uncertainty in the UL winds over the time period between the assessment and launch. Specifically, temporal wind pair databases are used to quantify wind change over a specified time interval at a given location; thereby reducing the level of uncertainty in vehicle performance assessments for commits to launch decisions. These databases consist of a certain number of wind pairs, where two wind profile measurements spaced by the time period of interest define a pair. NASA's Launch Services Program (LSP) requested development of wind pair databases for use in day-of-launch vehicle performance assessments. The purpose of this task is to generate temporal wind pair databases for five time intervals (0.75-, 1.5, 2-, 3- and 4-hour) at NASA's Kennedy Space Center located on the United States Air Force's Eastern Range (ER), Vandenberg Air Force Base on the USAF's Western Range (WR) and NASA's Wallops Flight Facility (WFF) from historical data at each location.

Multiple sources that measure UL atmospheric winds at the requested sites are used to generate the most robust databases possible. Databases are compiled using wind profiles from balloon systems, either rawinsondes or Jimspheres, or Doppler Radar Wind Profiler (DRWP) systems. Extensive quality control (QC) checks are applied on the data to remove unacceptable profiles, and statistical analyses of the resultant wind pairs from each site are performed to determine if the observed extreme wind changes in the sample pairs are representative of extreme temporal wind change.

The ER wind pair databases are complied using spliced profiles from the 915-MHz and 50-MHz DRWP systems. Using these systems yielded ~270,000 wind pairs for each time interval. For the WR, roughly 450 wind pairs for each time interval were complied using both of the rawinsonde and Jimsphere systems. The WFF pair databases consist of approximately 80 pairs for each time interval, as only rawinsonde measurements are available for this site.

The sample size for the ER and WR wind pair databases characterizes extreme wind change and both of these two databases are acceptable for use in spaceflight vehicle performance applications. However, due to the small sample size for each time interval at WFF, low confidence exists that the observed extremes in each time period characterize the extreme wind change that could occur at the site. Therefore, for any vehicle performance applications, the author's recommendation is to apply the extreme 4-hr wind change values for all time intervals of interest.

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1. Introduction

Space launch vehicle commit-to-launch decisions include an assessment of the upper-level (UL) atmospheric wind environment to assess the vehicle's controllability and structural integrity during ascent. These assessments occur at predetermined times during the launch countdown based on measured wind data obtained prior to the assessment. However, the pre-launch measured winds may not represent the wind environment during the vehicle ascent. Uncertainty in the UL winds over the time period between the assessment and launch can be mitigated by a statistical analysis of wind change over time periods of interest using historical data from the launch range. Without historical data, theoretical wind models must be used, which can result in inaccurate wind placards that misrepresent launch availability. Using an over-conservative model could result in overly restrictive vehicle wind placards, thus potentially reducing launch availability. Conversely, using an under-conservative model could result in launching into winds that might damage or destroy the vehicle. A large sample of measured wind profiles best characterizes the wind change environment. These historical databases consist of a certain number of wind pairs, where two wind profile measurements spaced by the time period of interest define a pair. The purpose of this task, sponsored by NASA's Launch Services Program (LSP), is to generate temporal wind pair databases for five time intervals (0.75-, 1.5-, 2, 3, and 4 hours) at NASA's Kennedy Space Center located on the United States Air Force's (USAF) Eastern Range (ER), Vandenberg Air Force Base on the USAF's Western Range (WR) and NASA's Wallops Flight Facility (WFF) from historical data at each location. The wind change statistics based on the historical data can be applied in UL wind assessments on the vehicle during day-of-launch operations.

2. Data Sources

UL wind measurements can be made from a variety of instrumentation systems. The most common, known as a rawinsonde, has the capability to measure the wind with a balloon-lofted instrumented package that transmits the data back to a ground-based receiving system. Rawinsondes typically have a rise rate of 1000 ft/min (5.1 m/s) and reach 100 kft (30.5 km) before the balloon bursts. Output from rawinsondes is usually present at pressure levels, which correspond to uneven altitude levels. To use rawinsonde data in assessing vehicle response, the data are linearly interpolated to 100-ft altitude intervals to fill in gaps where wind data were not reported.

Another balloon-based system that is used only at the ER and WR for space vehicle support makes high-resolution wind measurements through the use of a specially designed balloon known as a Jimsphere (Wilfong et al. 1997). There are two types of high-resolution wind measurement systems that can track Jimsphere ascent. One system uses ground-based radar to track a Mylar coated Jimsphere balloon while another system, known as Automated Meteorological Profiling System (AMPS) High Resolution Flight Element (HRFE), uses Global Positioning Satellite technology and a clear Jimsphere balloon to track ascent (Divers et al. 2000, Adelfang 2003, Wilfong et al. 2000). Each system has specific data processing software to determine wind speed and direction as the balloon ascends. The balloon itself is more rigid than a rawinsonde plus it contains roughness elements to reduce self-induced oscillation during ascent (Wilfong et al. 1997). The Jimsphere also contains a vent valve in order to maintain a constant volume as the balloon ascends. However, maintaining constant volume limits the altitude range the balloon can achieve. A Jimsphere can typically reach between 55-60 kft (16.7-18.3 km) (Wilfong et al. 1997). Jimsphere profiles are also used to develop wind profile climatologies for use in vehicle performance analyses and design trades.

Vertically pointing Doppler Radar Wind Profiler (DRWP) systems are ground-based instruments that transmit and receive electronic pulses that can be converted to wind velocity and direction. The DRWP transmitted frequency and antenna size dictates the altitude range sampled and the sampling interval. The ER has a 50-MHz and five 915-MHz DRWPs that, when their measurements are spliced together, can generate a wind profile from roughly 600-60,000 ft (0.183-18.3 km). Data from the spliced profile are interpolated to a 50-ft (15.2 m) altitude interval. Unlike balloon-based systems, the DRWP operates continuously, with the 50-MHz DRWP reporting measurements approximately every 5-mins and the 915-MHz DRWP reporting measurements approximately every 15-mins. Both DRWP systems produce wind profiles at vertical resolutions acceptable for launch vehicle assessments. These attributes yield orders of magnitude more profiles compared to balloon profiles available for developing temporal wind pair databases. The WR also has DRWPs, however MSFC NE could not integrate data from both systems in the time allotted in order to generate vertically complete profiles necessary for this task in the time allotted.

2.1. NASA Wallops Flight Facility

Rawinsondes provide the only source of wind data at WFF. Two databases of rawinsonde profiles from WFF were obtained for this task. The first was from the National Climatic Data Center (NCDC) Integrated Global Radiosonde Archive (IGRA) (Durre et al. 2006) data for the October 1963 through January 2000 period of record (POR). The IGRA data for WFF consists of balloons released from the National Weather Service. The other database of rawinsondes was obtained directly from WFF, has a POR of February 2000 through January 2013, and consists of rawinsondes released at the NWS site and at WFF in support of mission operations. The IGRA database includes the rawinsonde data that was directly obtained from WFF personnel, which implies that no reason exists to include the IGRA data post December 1999 in the WFF wind pairs database generated for this task.

2.2. USAF Western Range

Archived data from rawinsondes and Jimspheres were available for developing the WR wind pair databases. The data came from three sources: IGRA rawinsondes from January 1965 through January 2013, WR rawinsonde profiles from February 2008 through April 2012, and a Jimsphere database from January 1965 through September 2001. The time overlap between the IGRA and WR rawinsonde databases was necessary because the IGRA database contains only WR rawinsonde data. Whereas, the WR rawinsonde archive contains AMPS HRFE wind data in addition to rawinsonde data that is archived in the IGRA database. As stated earlier, the WR wind pair databases do not contain DRWP measurements because the DRWP systems required extensive time to process.

2.3. USAF Eastern Range

Data from the ER DRWP systems provide the largest sample size and are the sole source used for database development. The spliced ER DRWP profile database has a

POR of April 2000 through December 2009. This POR results from the availability of quality controlled (QC'd) data for both the 50-MHz and 915-MHz DRWP at the time of this task. No rawinsonde or Jimsphere data were used because adding these data would have only increased the sample size of the ER database by 0.5%.

3. Data Processing and Quality Control Procedures

Extensive QC of wind profile data were required to remove suspect data in individual profiles as well as in profile pairs. Automated and manual QC checks were applied on the data from each measurement source. The automated QC checks differed between the measurement sources and consisted of general and task-specific checks. The latter checks were necessary because all of the general QC checks evaluated the data in single profiles and did not check consistency within a profile pair. The development process rejected a profile that failed a given QC check. The following sections present details of the QC checks for each measurement system.

3.1. Rawinsonde

Rawinsonde data from all sources went through a two-step QC process. The rawinsonde data obtained from IGRA already had a set of QC checks performed on them (Durre et al. 2006). An additional set of more stringent QC checks was performed on all rawinsonde data based on a manual review of the IGRA data. The development process applied the following QC checks to each individual profile:

- At least ten altitudes that contain either wind or thermodynamic data must exist.
- Vector differences between adjacent wind measurements must be less than 100 kt.
- The mean wind speed over the entire profile must be less than 100 kt.
- Difference magnitudes between adjacent temperatures in the lowest 10,000 ft of the profile must be less than 20°C.
- All heights must increase.
- The minimum altitude must be positive.
- Dew points corresponding to temperatures must be ≥-60°C.

The development process first extracted wind pairs containing profiles that passed all initial QC checks. However, several more QC checks were applied on the data to check for data quality between profile pairs. The process removed a wind pair that contained one or two profiles that failed a QC check. The following QC checks were implemented to remove suspect wind pairs:

- Wind data with each profile in the pair must reach a minimum of 20,000 ft.
- Wind component change between adjacent altitudes (vertical wind shear) must not exceed 0.15 s^{-1}.
- More than 50% of wind data must exist in both profiles.
- Duplicate pairs were removed.
- Each wind pair was manually inspected for erroneous data.

The minimum altitude requirement of 20,000 ft (6,095 m) was based on the minimum altitude required to perform a launch vehicle assessment at the request of the end user. Rejecting profiles not containing at least 50% of the possible wind data eliminated the potential of having an artificially large temporal wind change at the same altitude over the two profiles due to a large interpolation in one of the profiles. A percentage check as opposed to an altitude range check was used due to the IGRA data being reported in pressure levels, which results in unequal altitude intervals and large data gaps inherently existing in valid profiles. This check also removed profiles that contained excessive vertical wind shear resulting from interpolating data over a large altitude interval. As part of the manual QC process any profiles that exhibited large interpolations not consistent with the other profile were removed. The duplicate pair QC check was necessary for the WR wind profiles due to using multiple sources of wind profile databases with overlapping POR. Several additional processing and QC checks for the WR data were performed due to the overlapping POR.

- Profiles from both sources were merged into a single subset and sorted temporally.
- Profiles ≤15 minutes apart were grouped and the profile reaching the highest altitude was included in the database.
- Unique profiles were then merged with the existing IGRA and RTAMPS database.

The last step entailed manually inspecting each pair. The development process implemented this step after a review of the maximum wind component change and probability distributions, independent of altitude, for each pair time interval. Temporal wind change analyses have shown that wind change extremes are typically correlated to time separation: the longer the time interval, the larger the extreme wind change magnitudes (Johnson, 2000). However, the WFF and WR wind component change at probability levels greater than 95% in the 0.75 and 1.5-hour pairs were ~50% greater than the corresponding maximum wind change at the same probability level in the 2- 3- and 4-hour pairs without manual QC. Manual inspection of the WFF and WR wind pairs for all time intervals revealed these questionable wind change values were associated with profile pairs occurring around 0000 UTC in data obtained from the IGRA database (Durre et al., 2006). This characteristic appeared in the 2-, 3- and 4-hour wind pairs for both WFF and WR. The differences observed in the questionable wind profiles seemed more characteristic of diurnal-scale wind change as opposed to short-time period wind change, which led to questioning the time stamp of each profile in the pair. An independent source provided a comparison to events of questionable wind change. Data from the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis project at the time period of interest were evaluated to determine if a large gradient in the winds existed over the time period. The majority of these cases did not corroborate with the NCEP data and, as a result, the wind pairs occurring near 0000 UTC that contained wind profiles from the IGRA source were removed from the generated database. The resultant temporal wind change distributions were better correlated as a function of time separation.

3.2. Jimsphere

The WR wind pairs include wind profiles from the both systems that use the Jimsphere balloon. Jimsphere wind profiles were generated during launch vehicle operations and were manually QC'd by technicians prior to distribution to launch vehicle operators. The manual QC checks were performed to remove suspect data for use in flight vehicle assessments (Divers et al., 2000). Additional automated QC checks were performed on the data for this task prior to combining with the rawinsonde data to determine where wind pairs existed:

- A profile was removed if its lowest altitude exceeded 400 ft or if the profile contained any decreasing altitudes.
- All variables (altitude, wind speed, and wind direction) were removed if at least one variable was missing.
- All data were removed after the first altitude containing missing data.
- Any linear wind component interpolations at the top of the profile were removed.

The selected wind pairs for the WR can be made up of two Jimspheres, two rawinsondes, or a Jimsphere and a rawinsonde. The issue with the Jimsphere/rawinsonde combination is that a difference exists in the smallest resolvable wavelengths between these two wind profiles due to their sampling intervals. The small-scale wavelengths were removed through a filtering algorithm in order to maintain an equivalent effective vertical resolution between the rawinsonde and Jimsphere systems (Wilfong et al., 1997). An 800-ft filter was applied to the Jimsphere based on a power spectrum analysis of the rawinsonde data. Filtering the Jimsphere data was necessary to use wind profiles from either system interchangeably in assessing wind affects on vehicle performance (Wilfong et al.1997).

After filtering the Jimsphere profiles, the QC checks for acceptable wind pairs and the manual QC process defined in section 3.1 were applied to the data.

3.3. DRWP

The ER wind pairs consist of profiles from the DRWP systems. These systems are designed to operate continuously with limited manual QC processing. The algorithms and methodologies in Barbre (2012) and Lambert et al. (2003) detail the QC process on the 50-MHz DRWP (D-50) data and the 915-MHz DRWP (D-915) automated QC process, respectively. Additional QC on the D-915 data included removing profiles with duplicate timestamps, filling temporal data gaps greater than 15 minutes, and checking for correct altitude progression. The resultant POR of temporal overlapping QC'd D-50 and D-915 data extends from April 2000 to December 2009.

The next step after data QC entailed creating a single profile by splicing the two DRWP profiles at the altitude where the top of the D-915 profile (20,013 ft or 6,100 m at most) and the bottom of the D-50 profile (approximately 8,202 ft or 2,500 m) meet or overlap. Before generating the spliced DRWP profiles, the temporal and spatial (vertical) criteria are determined and applied to all DRWP profiles because the individual profiles had to match in both domains before splicing (Barbre 2013). The D-50 archive contains measurements at 492-ft (150-m) intervals every five minutes prior to an instrument upgrade in 2004 and 475-ft (145-m) intervals every three minutes thereafter. The D-915 archive contains measurements at 331-ft (101-m) intervals roughly every 15 minutes. The spatial criterion for the blended profiles is 164 ft (50 m) with the temporal criterion based on the time interval of the D-50 measurements.

An algorithm was applied to the data to splice the D-50 and D-915 profiles into one using each of the five D-915s. First, for each D-50 timestamp, the algorithm found the closest corresponding timestamp in each of the D-915 profiles. Next, the algorithm interpolated the D-50 and D-915 profiles to 164-ft (50-m) spacing in the altitude range 328-61,024 ft (100-18,600 m), which is the lowest observation of the D-915s to the highest observation of the D-50. Then, the algorithm counted the number of data gaps from each instrument, flagged 984-ft (300-m) data gaps with the D-50 and 1640-ft (500-m) data gaps with the D-915, and linearly interpolated wind components within un-flagged gaps. Both profiles contained data placeholders at the same altitudes, with a transition region between the two profiles typically at altitudes around 6,562-9,843 ft (2,000-3000 m). The algorithm then spliced the two profiles using a methodology that varied slightly based on the data coverage of the two profiles within the transition region. If a D-915 profile overlapped the D-50 profile, then the algorithm combined the D-50 and D-915 wind components within the transition region using a weighting scheme that provided greater weight to the D-915 at lower altitudes and greater weight to the D-50 at higher altitudes. If a D-915 profile did not reach the D-50 profile, then the algorithm linearly interpolated the winds between the highest altitude of the D-915 profile and the lowest altitude of the D-50 profile provided the QC algorithm did not flag the gap. Each spliced profile contained winds exclusive to the D-915 below the transition region, derived winds within the transition region, and winds exclusive to the D-50 above the transition region. Splicing the D-50 and individual D-915 profiles produces up to five DRWP wind profiles at a given timestamp in the archive, depending on the QC process and how many D-915s were operating.

The individual spliced profiles were then combined to generate a single composite DRWP profile representing the wind environment at a given timestamp. The individual spliced profiles only differed below the lowest altitude of the D-50 profile. An algorithm was developed by MSFC NE that generated composite winds at each altitude starting at 492-ft (150-m) and ending at 60,532-ft (18,450-m). The algorithm omitted data at the lowest D-915 altitude and the highest D-50 altitude due to ground clutter effects and questionable shears, respectively. The algorithm first computed a mean reference wind using the individual spliced profiles with valid winds at each altitude. Next, vector differences between the winds from each of the individual spliced profiles and the reference wind were used to derive weights corresponding to each of the profiles. Summing the product of the weights and wind components from all individual profiles produced the composite wind at each altitude. Above the lowest reporting altitude, the algorithm computed the reference wind as the mean of the reference wind described above and the composite wind at the previous altitude.

A subsample of the DRWP archive was produced according to specified guidelines. The end user specified an altitude requirement that the wind profile had to contain data at all altitudes from 820-20,000 ft (250-6,096 m). In addition, MSFC NE linearly reduced wind components from altitudes below the lowest reporting altitude, which ranged from 492-820 ft (150-250 m), to no wind at 0 ft (0 m). Profile tops extended as high as 60,532 ft (18,450 m).

4. Wind Pair Development and Analysis

The criteria to select pairs, the resultant number of wind pairs at each location, statistical analyses of the sample sizes, and distributions of extreme wind changes are presented in the following sections.

4.1. Criteria to select pair

Constraining the pair selection to the exact time spacing with the balloon-based WFF and WR profiles limits the number of pairs since balloons are released infrequently. Therefore, for each pair the time range was expanded by +/- 15 minutes to increase the wind pair sample size. For example, profile pairs spaced between 2.75 to 3.25 hours were treated as 3-hour pairs. For the ER, two profiles defined a pair if the desired time separation of the pair +/- two minutes separated the profiles' timestamps. For example, a 0.75-hour (45-minute) pair has two profiles spaced anywhere from 43-47 minutes apart. The pair selection process used a two-minute window because a large number of DRWP profiles existed and at least three minutes existed between adjacent DRWP profiles.

4.2. Sample Size

Table 1 presents the number of pairs at each time interval and location. The disparity in the magnitude of samples at the ER is due to the continuous operation of the DRWP versus the discrete measurements from the balloon systems used at WR and WFF. The WR's history of supporting space launch operations that require frequent balloon releases attributes to the difference between the number of WR and WFF pairs.

Table 1. Sample size of wind pairs at each location.

Time Interval (hours)	***ER***	***WR***	***WFF***
0.75	273,265	435	78
1.5	260,878	401	54
2	297,490	548	75
3	273,189	508	127
4	276,108	366	74
TOTAL	1,380,930	2258	408

4.3. Statistical Analysis/Confidence Bounds

The most frequent application of wind pair databases is to apply the empirical maximum zonal (u) and meridional (v) wind change components of each profile into a persistence assessment to determine the effects of wind change over a specific time period on vehicle performance (Smith et al. 1992). Therefore, a large sample size must exist in order to capture the largest range of maximum wind change possible. Several analyses were conducted to determine how well the sample population at each location characterized the wind change extremes.

The analyses results quantify the distribution and the confidence bound (CB) in the empirical maximum wind change from the various sample sizes of each pair set. Extreme wind change population distributions are usually non-Gaussian (Merceret 1997), so the use of an extreme theoretical probability function was used to fit the data. The generalized extreme value (GEV) probability distribution function (PDF) (Coles, 2001, Kotz and Nadarajah, 2000) provided a good fit of the extreme u- and v-component wind changes in each pair up to roughly the 99th percentile level. The GEV PDF is expressed by:

$$y = f(x|\, k, \mu, \sigma) = \left(\frac{1}{\sigma}\right) exp\left\{-\left[1 + k\frac{(x-\mu)}{\sigma}\right]^{-\frac{1}{k}}\right\}\left[1 + k\frac{(x-\mu)}{\sigma}\right]^{-1-\frac{1}{k}}$$

for $k \neq 0$ and $1 + k\frac{(x-\mu)}{\sigma} > 0$

where *x* represents each value in a distribution of wind changes, and *k*, *μ*, and *σ* denote the scale, shape, and location parameters, respectively, of the GEV estimate. Using the results from the GEV, 95% CB at various percentile levels were calculated using the Asymptotic Distribution of Percentiles (ADP) method (DasGupta 2008). The ADP equation is a function of the CB, sample size and percentile level of interest. The analysis uses the 95% CB as a conservative approach to assess the range of extreme wind change for selected percentile levels.

Distribution plots for the maximum change in wind component magnitude at each time interval and location are presented in Figures 1–15: the ER plots are in Figures 1–5, the WR plots are in Figures 6–10, and the WFF plots are in Figures 11–15. The cumulative probability, drawn from the probability density function (Wilks 2006), is along the y-axis and the magnitude of the wind component's change is along the x-axis. The sample size of the pairs is correlated to the width of uncertainty at the 95% CB for the highest percentile levels in the sample population. As the sample size increases the width of uncertainty at the 95% CB decreases. In addition, a small probability density at a selected percentile level increases the width of uncertainty. Figure 13, the WFF 2-hour pairs plot, shows this attribute – where the 95% CB in the v-component change are significantly greater than the bounds in the corresponding u-component change even though the sample sizes for both u- and v-changes are the same.

The width of uncertainty in the CB for all the ER pairs (Figures 1–5) is small due to the large sample size. The deviation of the CB from the empirical distribution above the 95th percentile level is an artifact of the CB being calculated from the GEV function, which does not fit the empirical distribution well. However, the poor fit is not an issue since the sample size is large enough to justify using the empirical percentiles for almost any flight vehicle assessment.

For the WR and WFF samples, Figures 6–10 and 11–15, respectively, the 95% CB range of uncertainty increases as the sample size decreases. The WR 95% CB range of uncertainty at the sample size's maximum empirical probability level was approximately 30 kt for both wind components in all the pairs except for 4 hours (Figure 10) where the range of uncertainty is ~80 kt. Because of the large uncertainty at the extreme empirical percentile in the 4-hour pairs, another approach was applied to quantify the confidence of the empirical wind change data. This approach uses a function from Smith and Adelfang (1998) that approximates the probability level of a sample population with a specified sample size to a probability level of the universal population. The function makes no assumption to the form of the probability distribution function of the wind change and is defined as:

$$P_u = 1 + \left[(n-1) - \frac{n}{P_s}\right] P_s^n$$

where P_u is the probability that the sample contains the universal population at the sample probability P_s and the sample size, *n*. Stated another way; a certain sample size is required to be P_u percent confident the sample contains the P_s value of the universal population. Table 2 presents the confidence level of the universal population for various sample probability levels based on the sample size in each WR wind pair interval. For the 366 4-hour wind pairs, there is 88.1% confidence that the pairs contain the 99th percentile of wind change during this time interval. The confidence level exceeds 90% for the other four time periods. These samples are large enough for most vehicle performance applications; however, a low confidence exists that these samples capture wind changes at extreme (e.g., > 99th percentile) levels.

Table 2. Confidence levels of the universal population for arbitrarily selected sample probability levels and the WR sample size for each wind pair time interval (Smith and Adelfang 1998).

Sample Probability	Time Interval (Sample Size)				
	0.75 hours (435)	1.5 hours (401)	2 hours (548)	3 hours (508)	4 hours (366)
0.500	1	1	1	1	1
0.750	1	1	1	1	1
0.900	1	1	1	1	1
0.950	0.9999999951	0.9999999742	1	0.9999999999	0.9999998576
0.990	0.9318892422	0.9102472336	0.9734932962	0.9628265943	0.8813414653
0.995	0.6400217131	0.5960258712	0.7592780050	0.7215858165	0.5466402874
0.999	0.0710955543	0.0617397316	0.1050219721	0.0925644635	0.0525946042

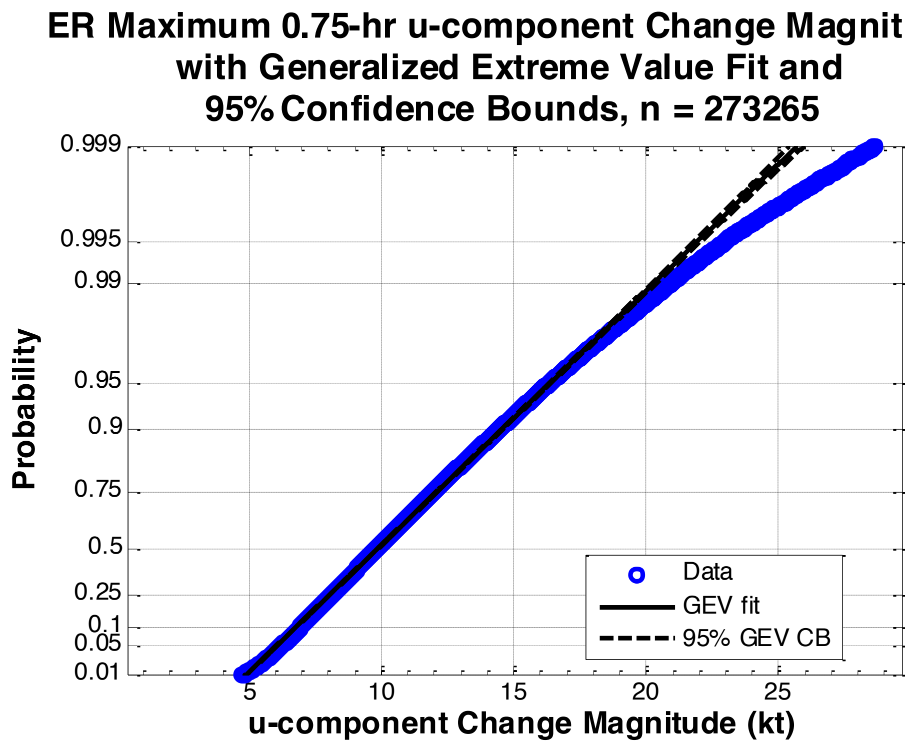
The WFF samples contain the smallest number of pairs of the three locations. Due to the small sample sizes for each time period, the 95% CB for the observed wind change extremes (~>40 kt) have a large uncertainty, which is more pronounced for the v-component (Figures 11–15). At each time period the 95% CB for the v-component wind change range is at least 40 kt. The maximum 4-hour v-component wind change of 74 kt exists at the 98th percentile level in the sample population's distribution. The 95% CB at the 98th percentile level ranges from 40.2 to 89.3 kt.

Table 3 presents confidence levels of the universal population for various sample probabilities based on the WFF sample size. A 16.9% confidence exists that the 4-hour pairs contain the 99th percentile of all wind changes during this period. The confidence levels range from 10-36% at the 99th percentile for the other pairs. Due to the low confidence that the sample contains extreme wind changes and large uncertainty in the 95th confidence intervals at probability levels above 95%, the recommendation is to apply the extreme 4-hour wind component change for all time change intervals of interest in vehicle performance evaluations. Applying this recommendation produces more conservative results for shorter time periods, while generating more under-conservative results as the time period approaches 4-hours.

Table 3. Confidence levels of the universal population for arbitrarily selected sample probability levels and the WFF sample size for each wind pair time interval (Smith and Adelfang 1998).					
Sample Probability	**Time Interval (Sample Size)**				
	0.75 hours (78)	**1.5 hours (54)**	**2 hours (75)**	**3 hours (127)**	**4 hours (74)**
0.500	1	1	1	1	1
0.750	0.9999999951	0.9999965954	0.9999999889	1	0.9999999854
0.900	0.9973926911	0.9763302566	0.9965467741	0.9999766603	0.9962087600
0.950	0.9065758090	0.7592069517	0.8944046852	0.9886106975	0.8900295154
0.990	0.1836371177	0.1018337236	0.1729083269	0.3629948281	0.1693552801
0.995	0.0584855478	0.0301293767	0.0545718214	0.1332461521	0.0532887329
0.999	0.0028550441	0.0013823282	0.0026435283	0.0073642623	0.0025747404

Table 4 presents confidence levels of the universal population for various sample probabilities based on the ER sample size. The confidence level is 100% for all time periods.

Table 4. Confidence levels of the universal population for arbitrarily selected sample probability levels and the ER sample size for each wind pair time interval (Smith and Adelfang 1998).					
Sample Probability	**Time Interval (Sample Size)**				
	0.75 hours (273,265)	**1.5 hours (260,878)**	**2 hours (297,490)**	**3 hours (273,189)**	**4 hours (276,108)**
0.500	1	1	1	1	1
0.750	1	1	1	1	1
0.900	1	1	1	1	1
0.950	1	1	1	1	1
0.990	1	1	1	1	1
0.995	1	1	1	1	1
0.999	1	1	1	1	1



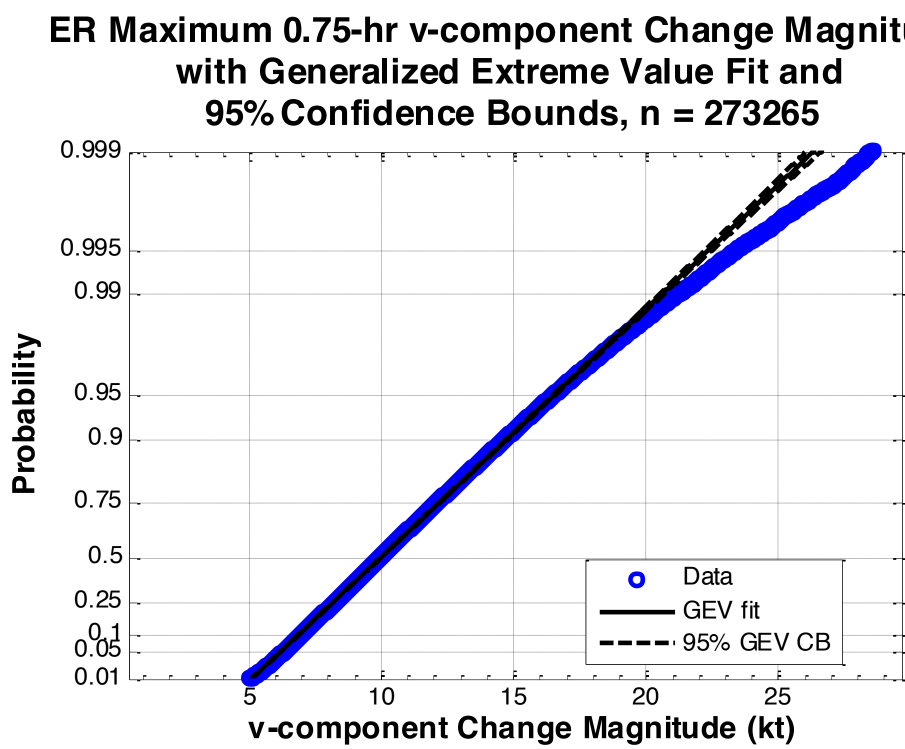
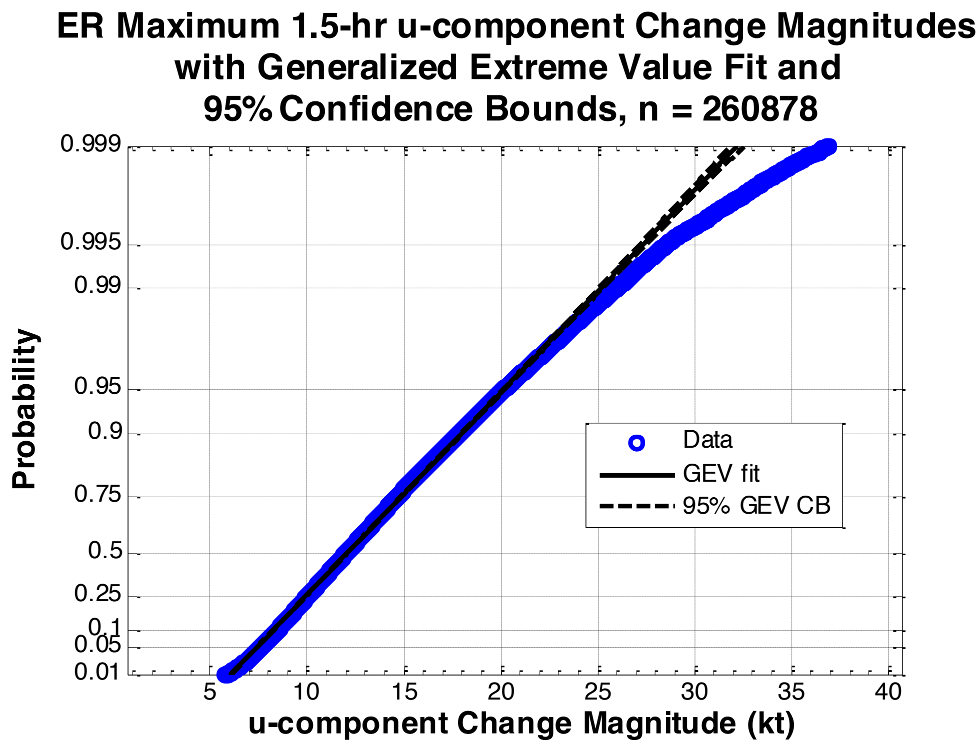


Figure 1. ER maximum wind change from the 0.75-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 273,265.



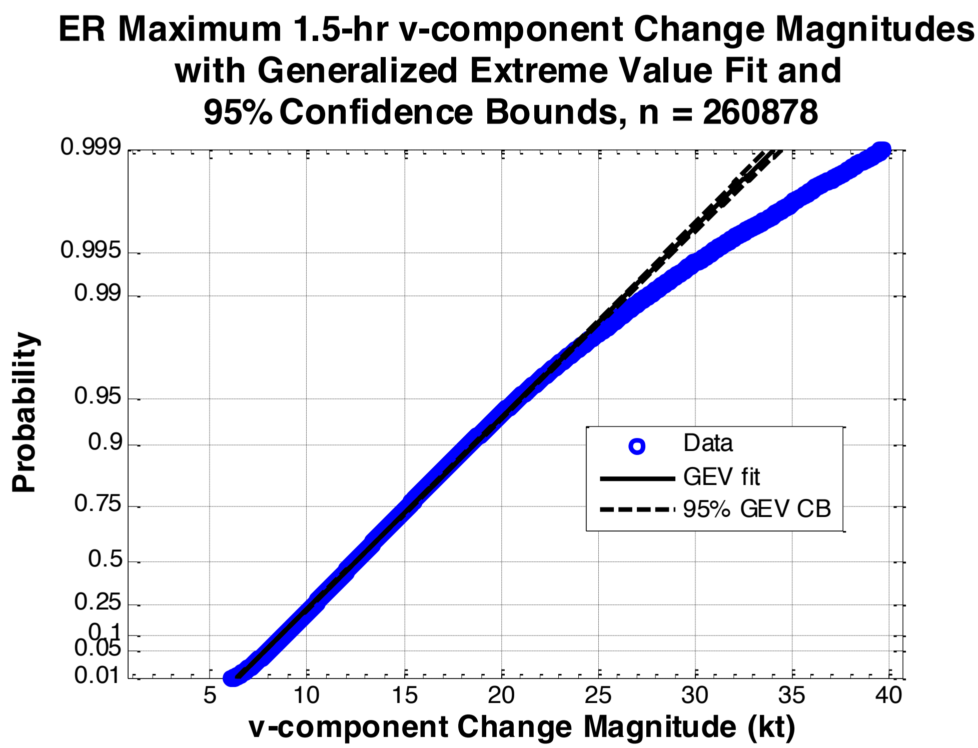
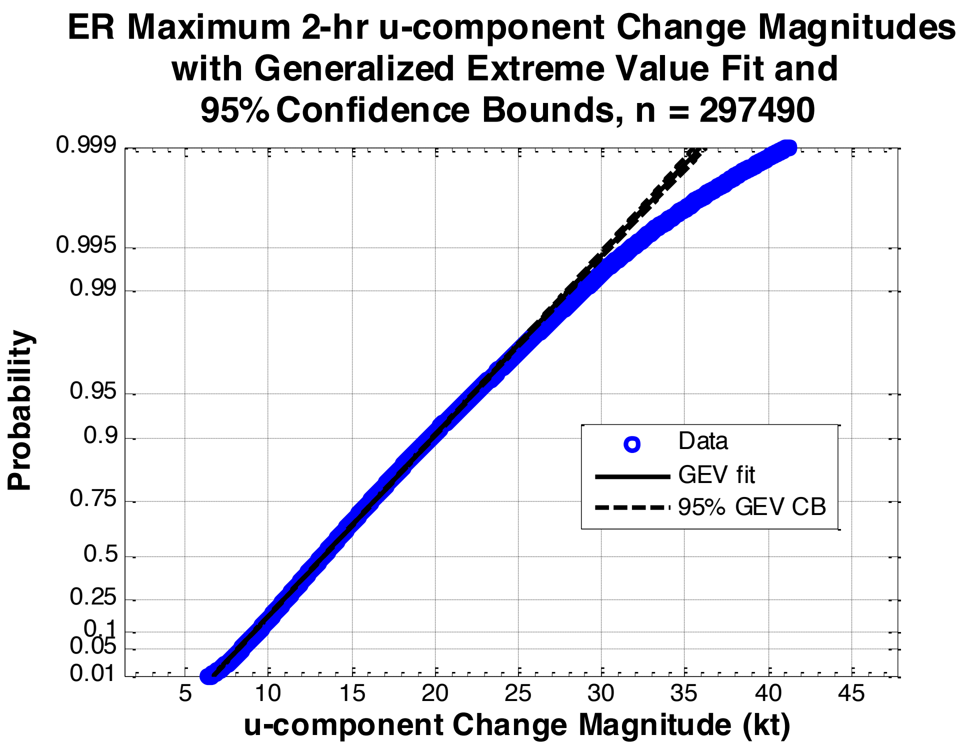


Figure 2. ER maximum wind change from the 1.5-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 260,878.



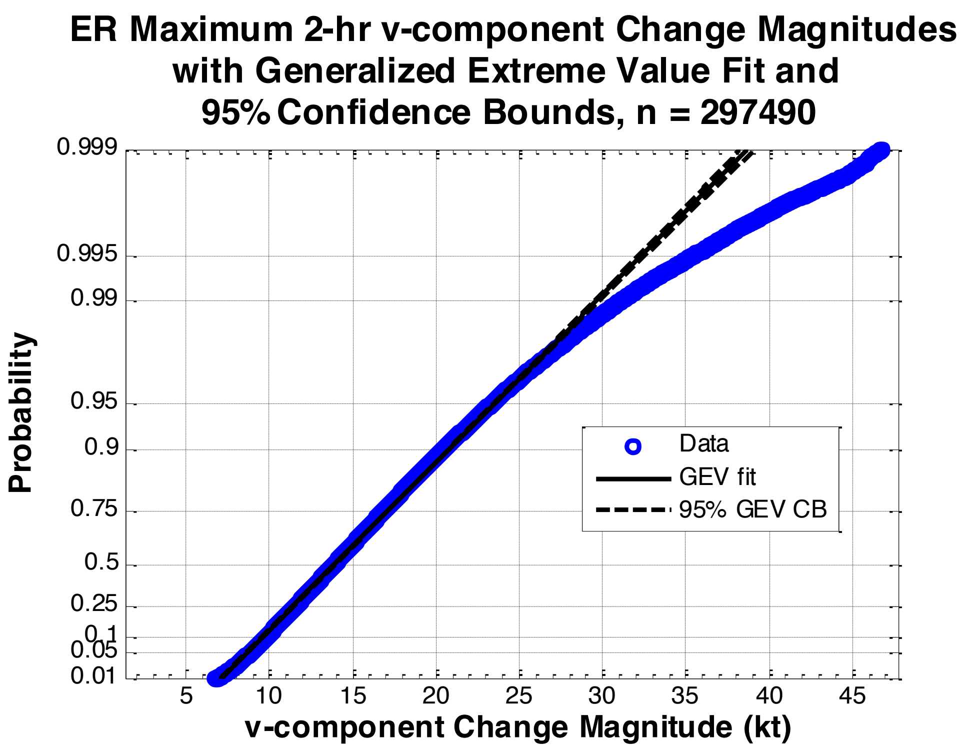
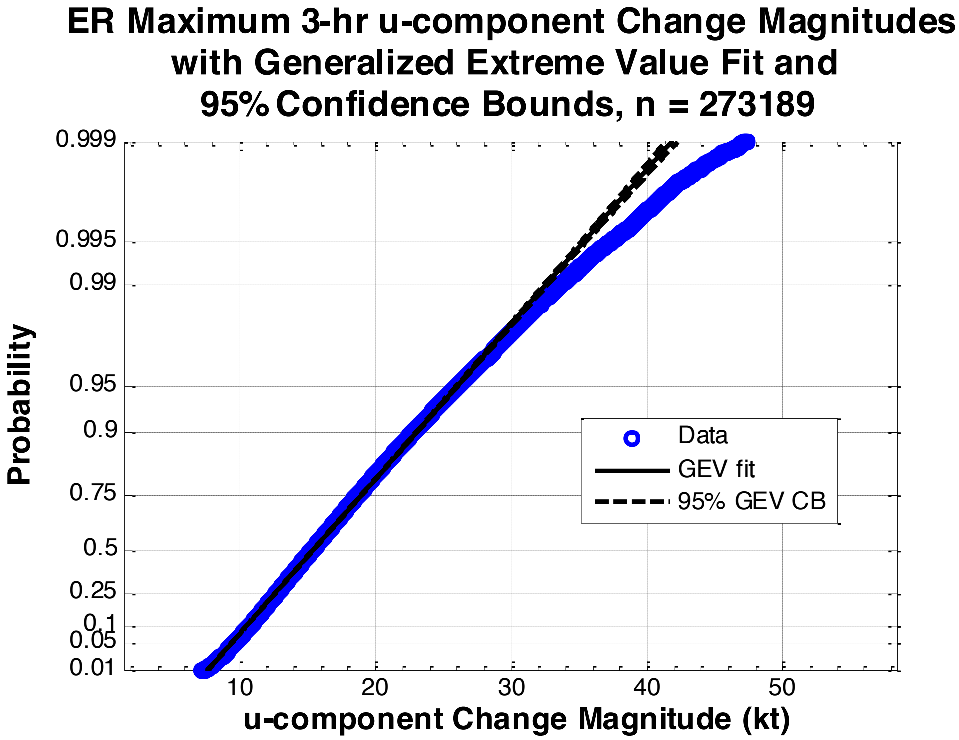


Figure 3. ER maximum wind change from the 2-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 297,490.



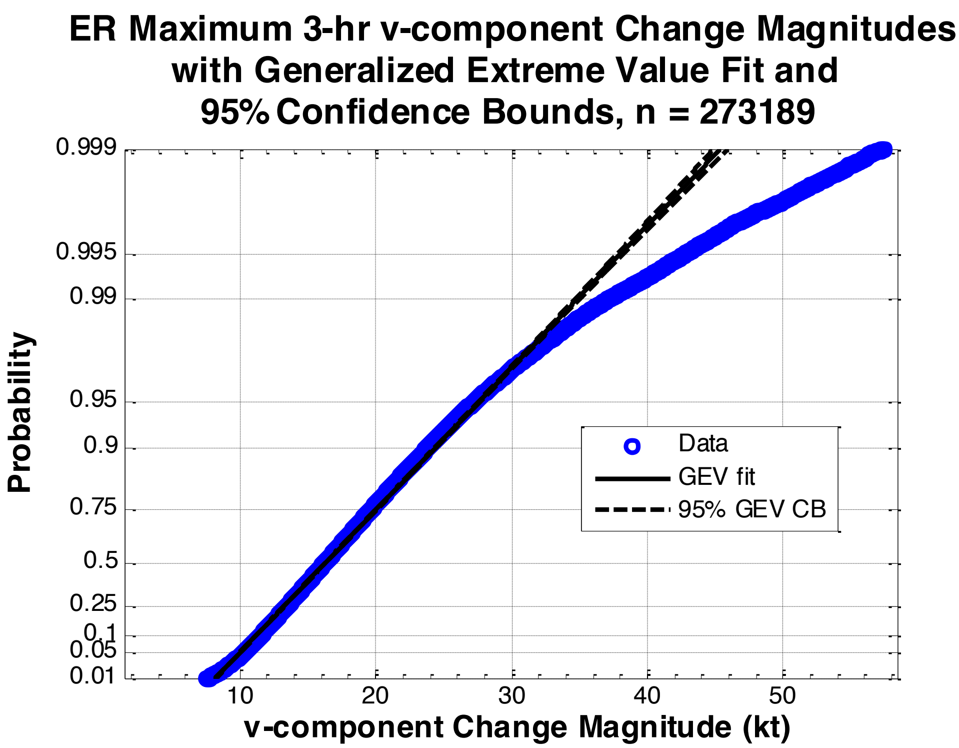
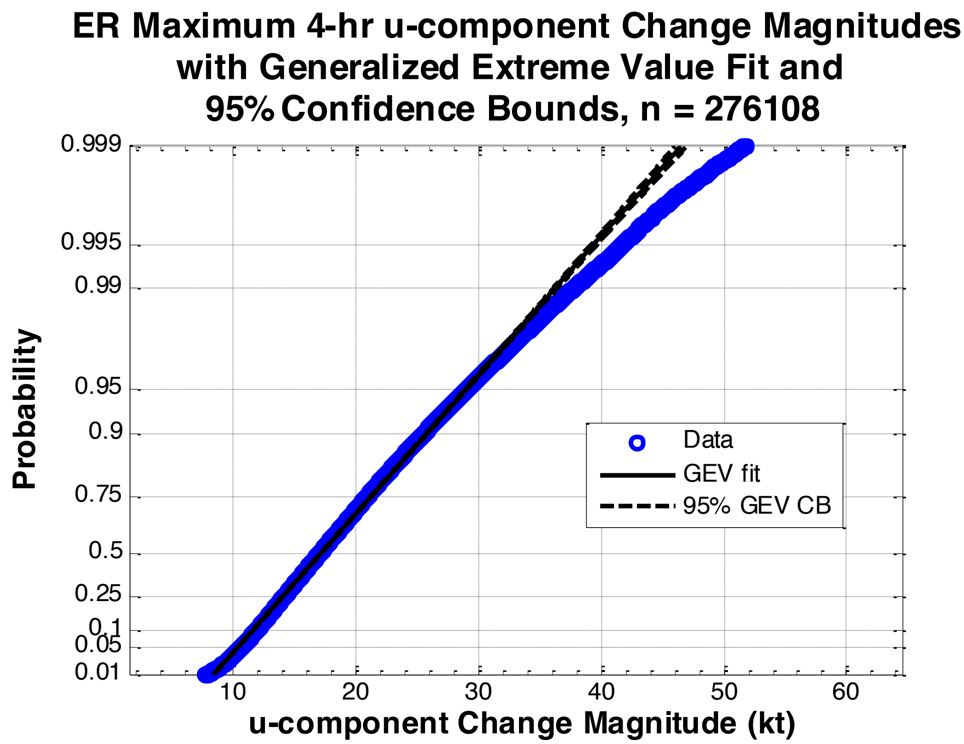


Figure 4. ER maximum wind change from the 3-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 297,490.



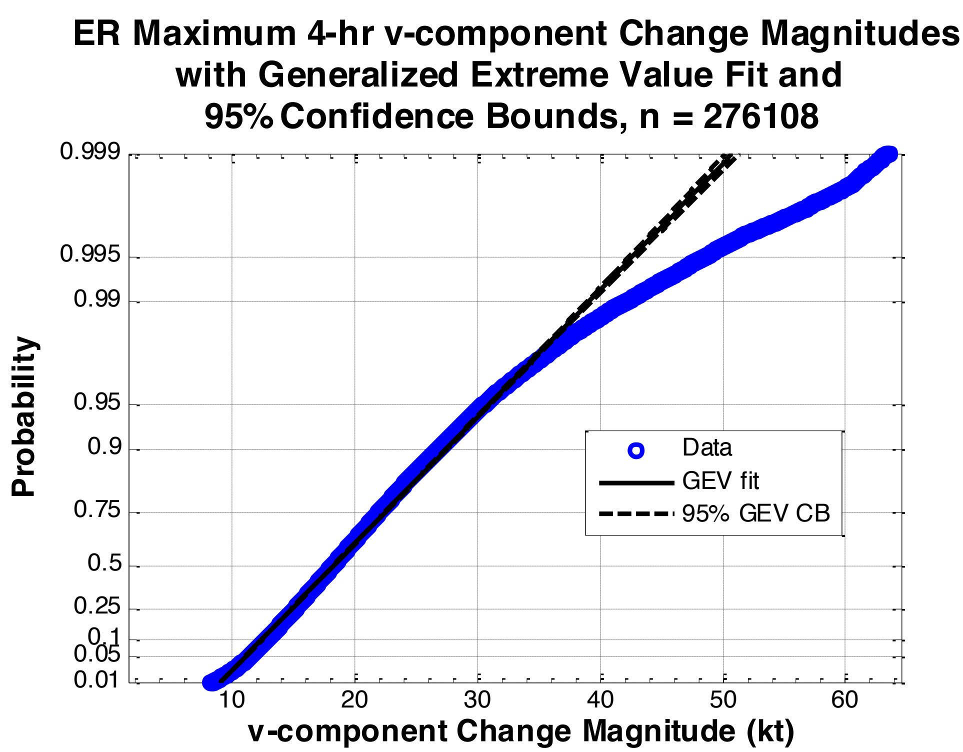
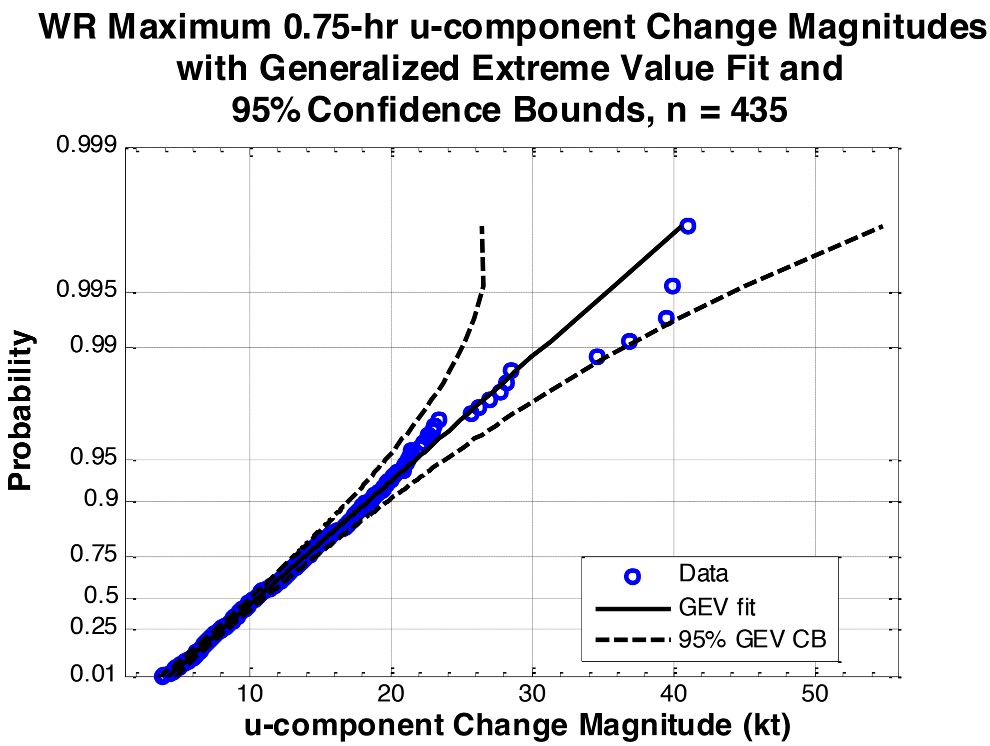


Figure 5. ER maximum wind change from the 4-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 276,108.



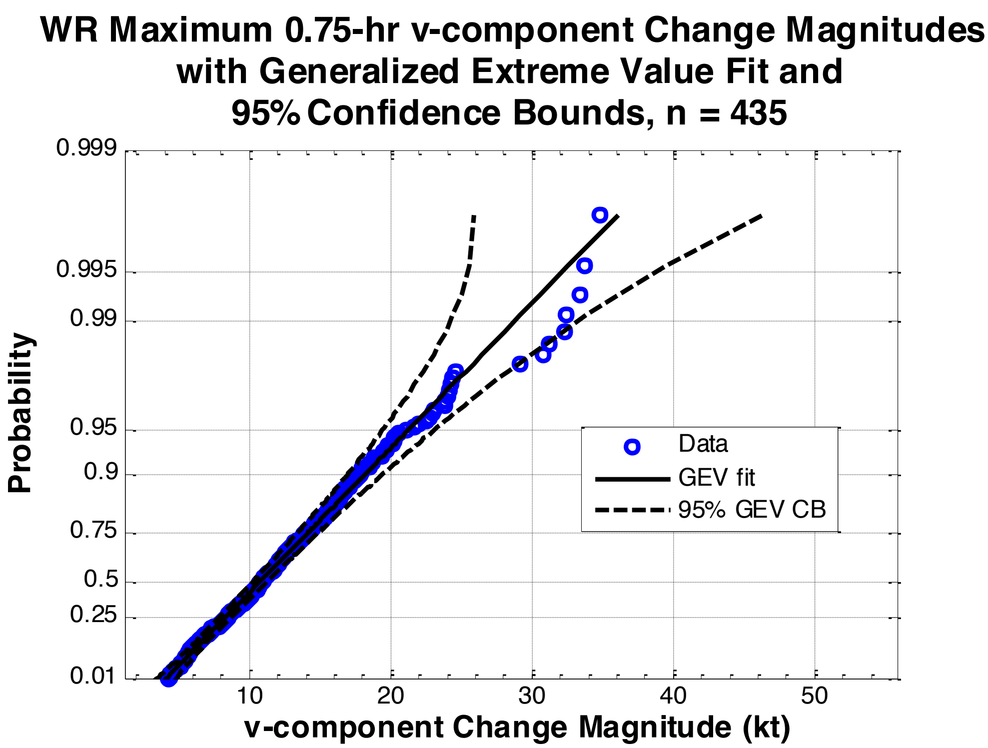
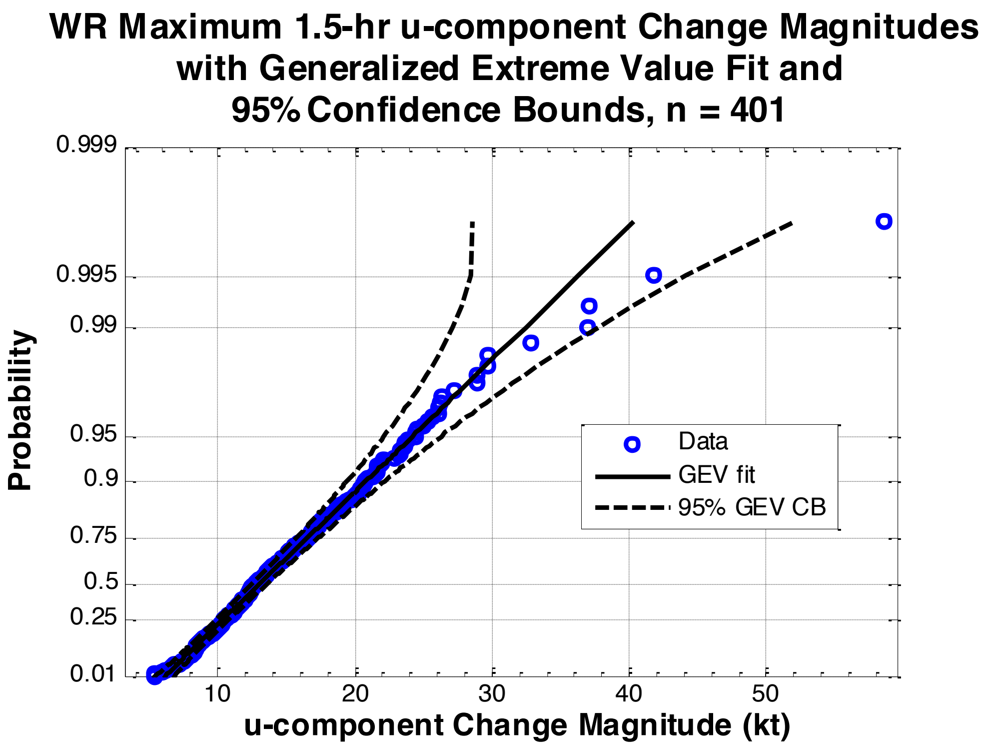


Figure 6. WR maximum wind change from the 0.75-hr wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 435.



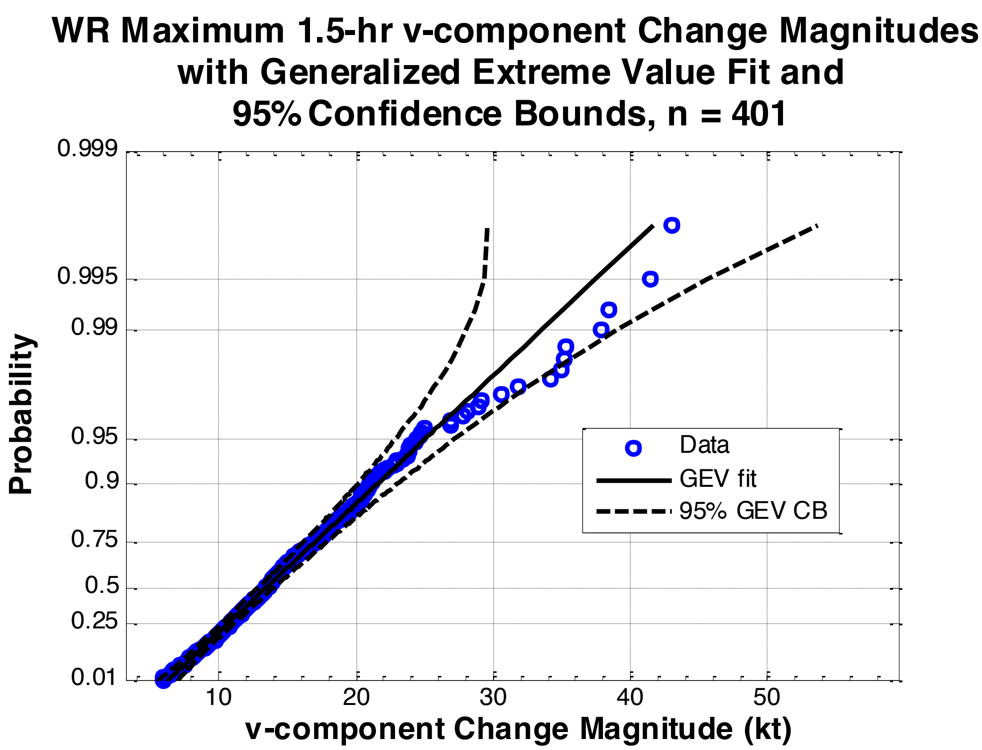
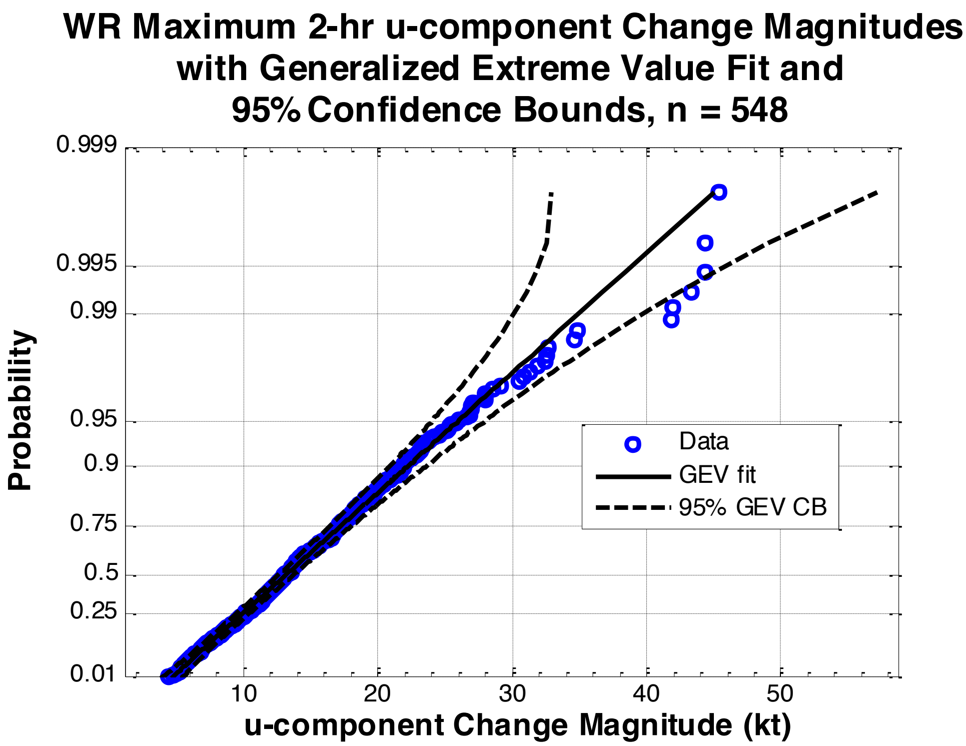


Figure 7. WR maximum wind change from the 1.5-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 401.



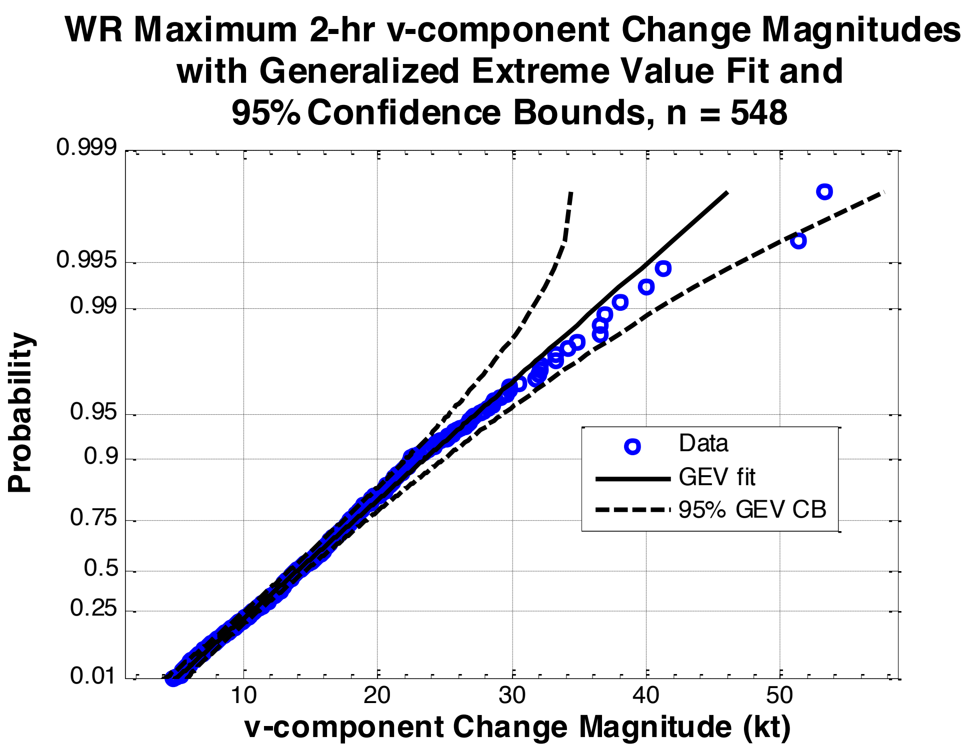
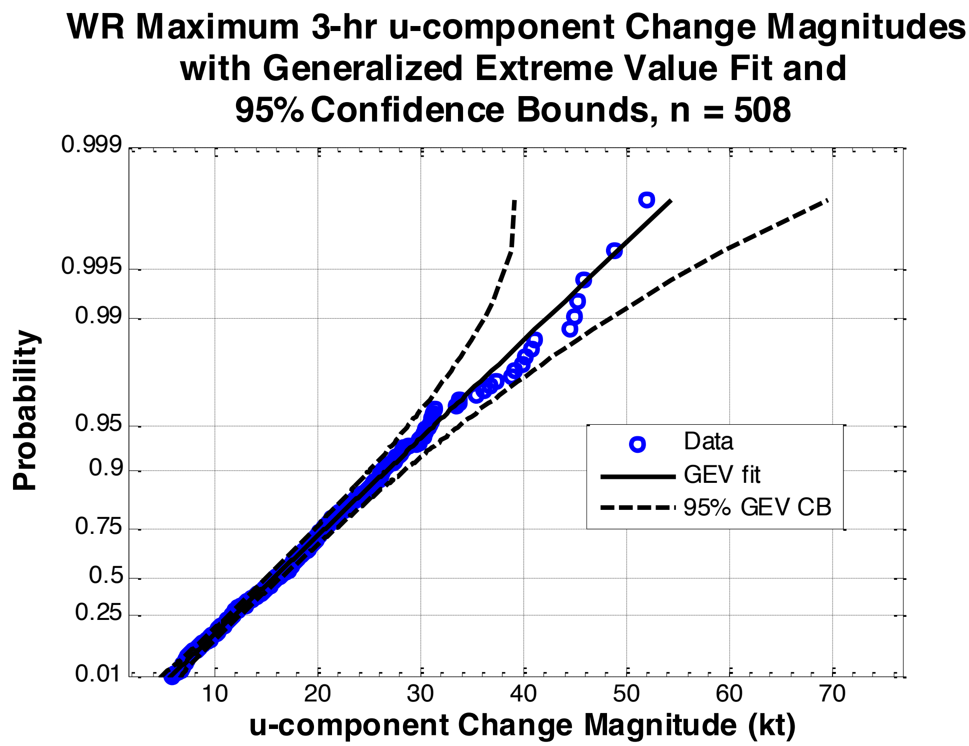


Figure 8. WR maximum wind change from the 2-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 548.



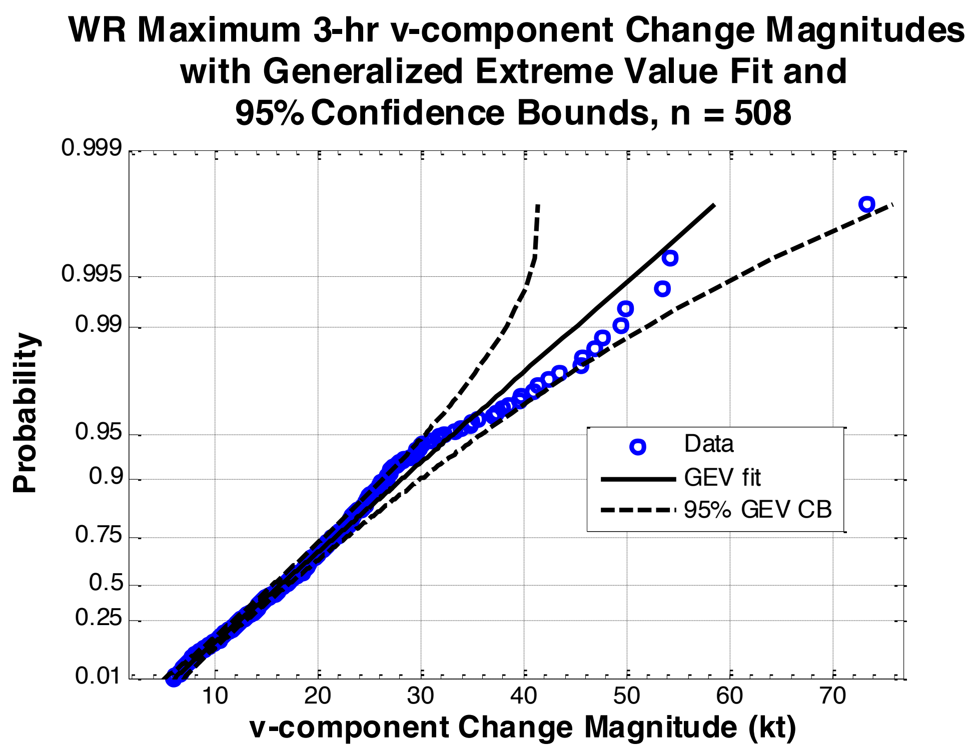
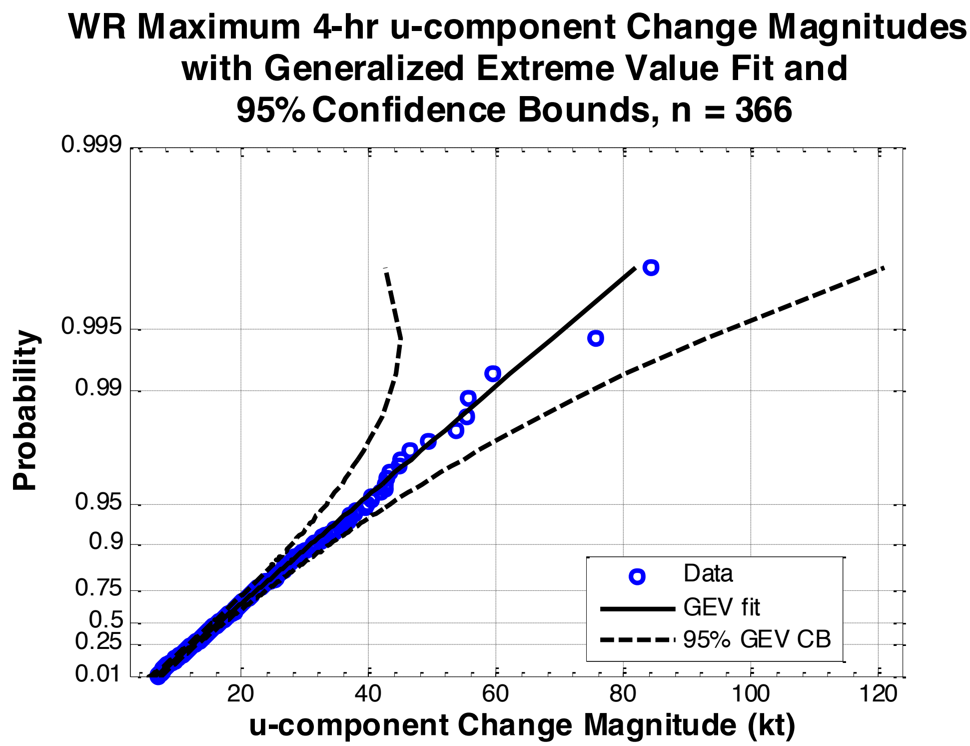


Figure 9. WR maximum wind change from the 3-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 508.



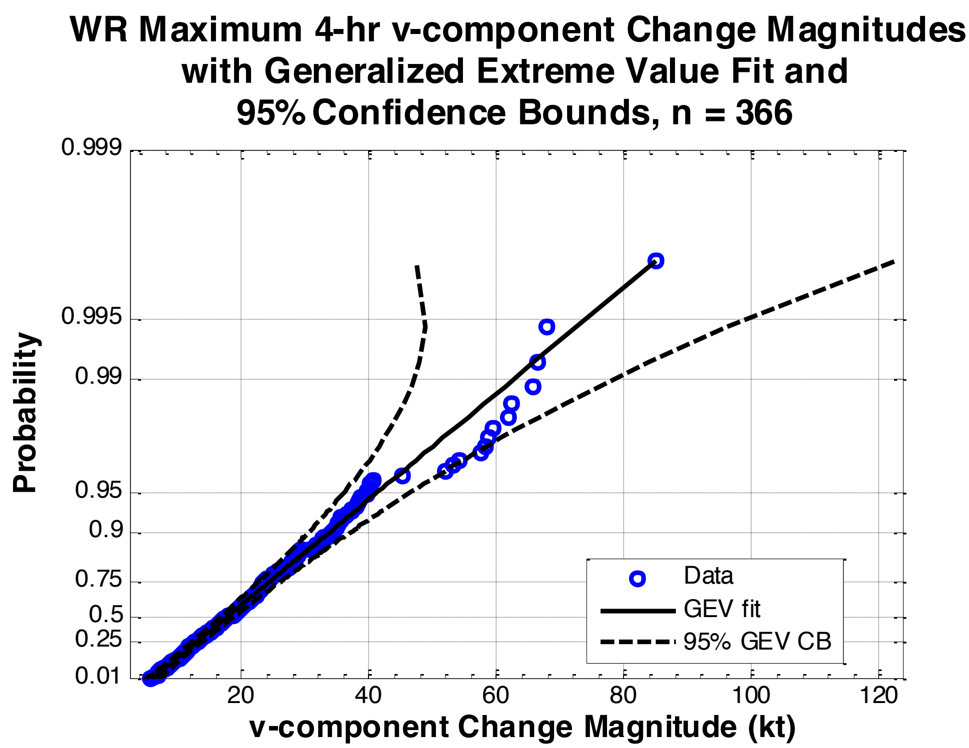
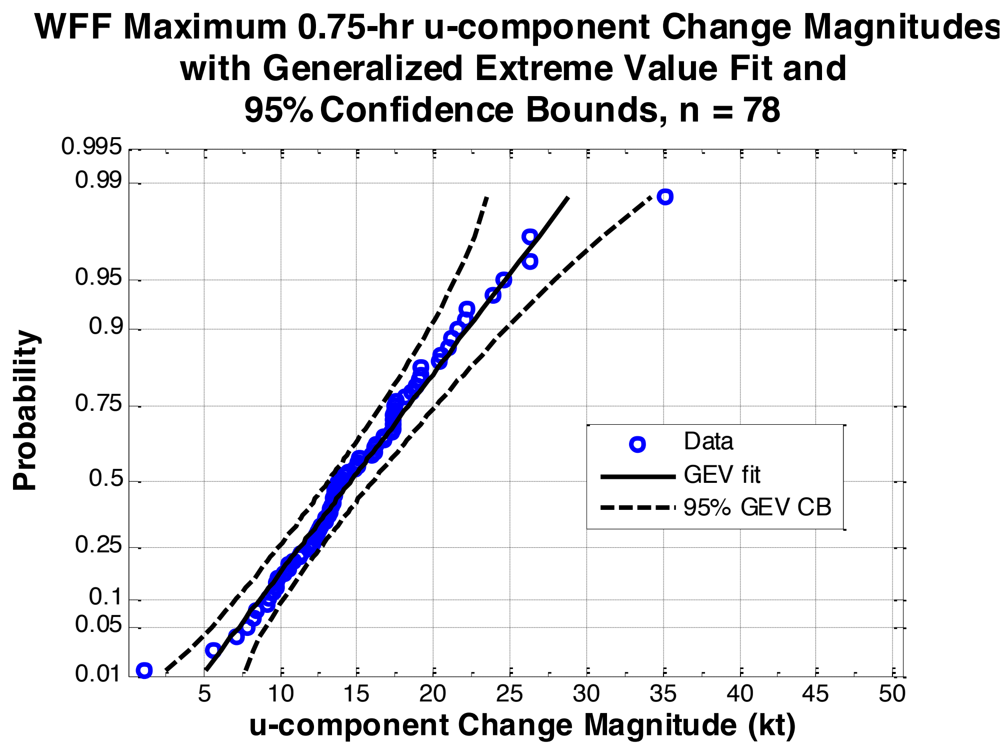


Figure 10. WR maximum wind change from the 4-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 366.



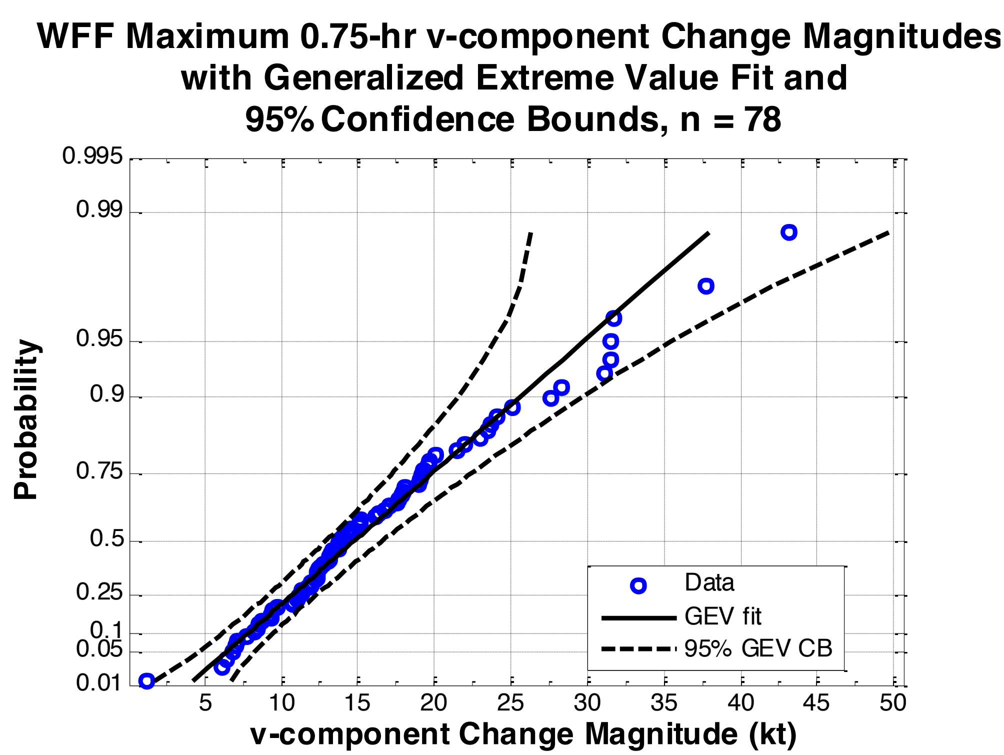
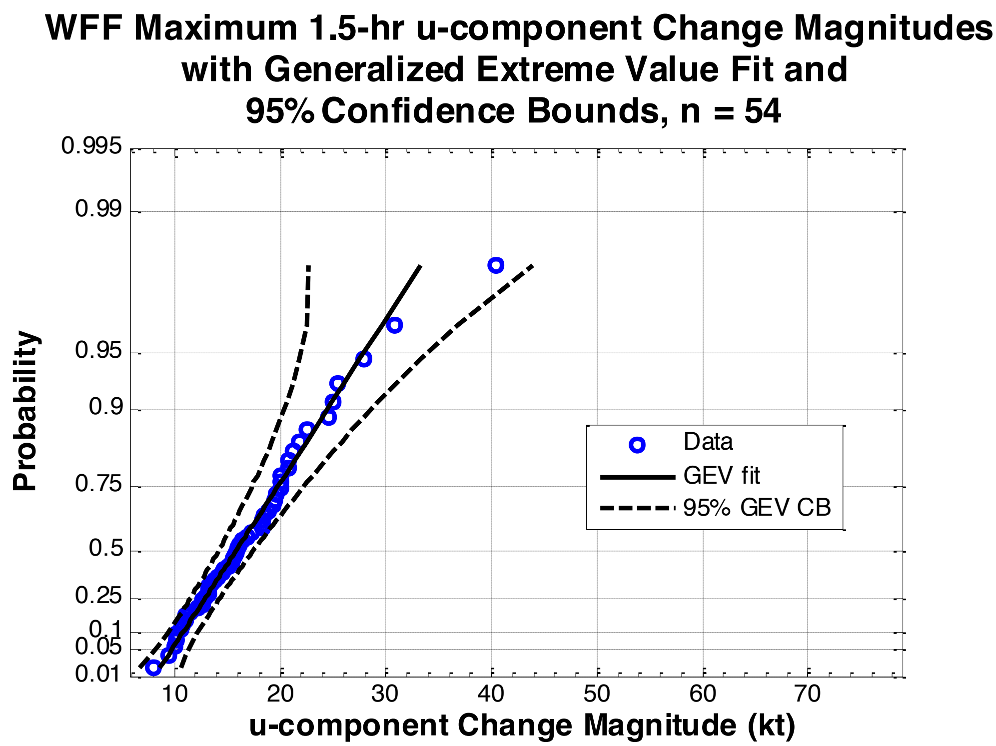


Figure 11. WFF maximum wind change from the 0.75-hr wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 78.



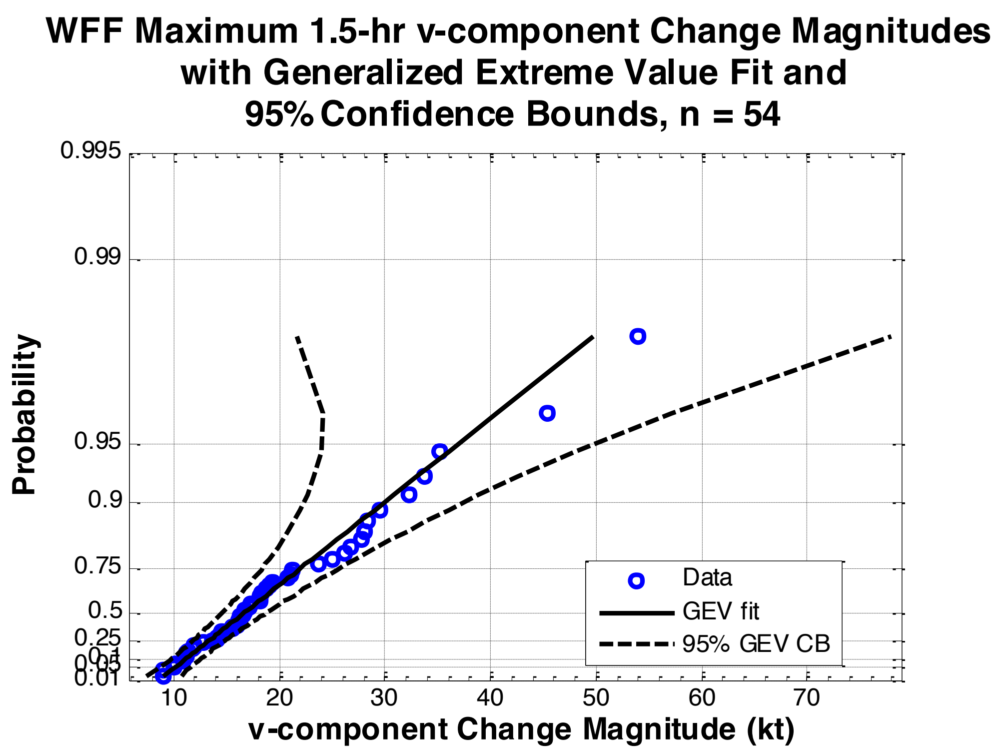
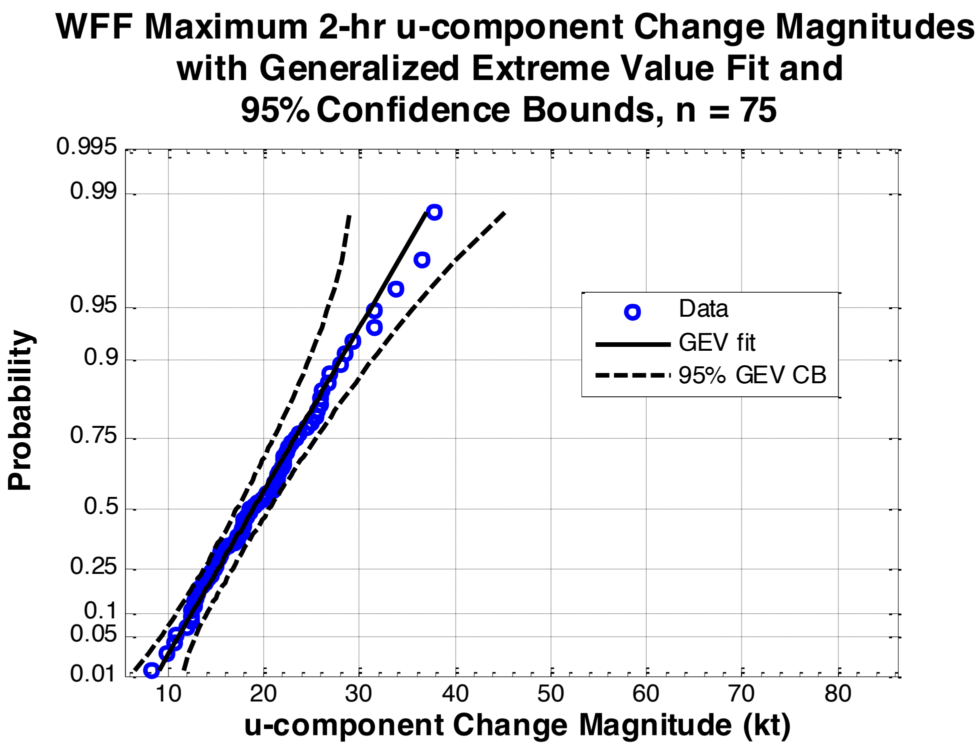


Figure 12. WFF maximum wind change from the 1.5-hr wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 54.



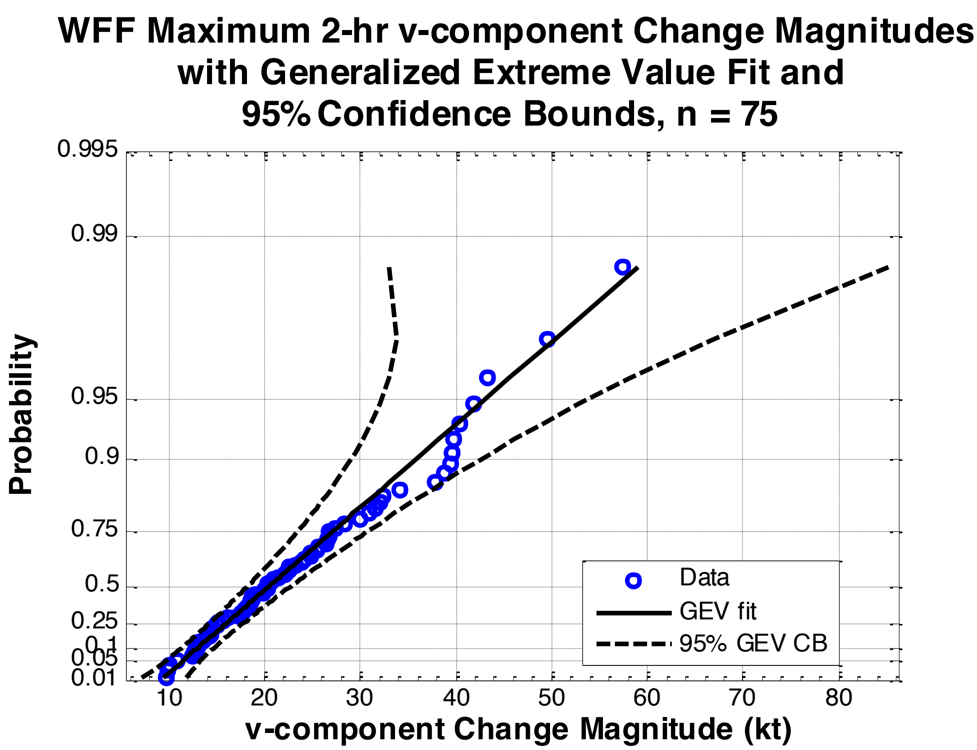
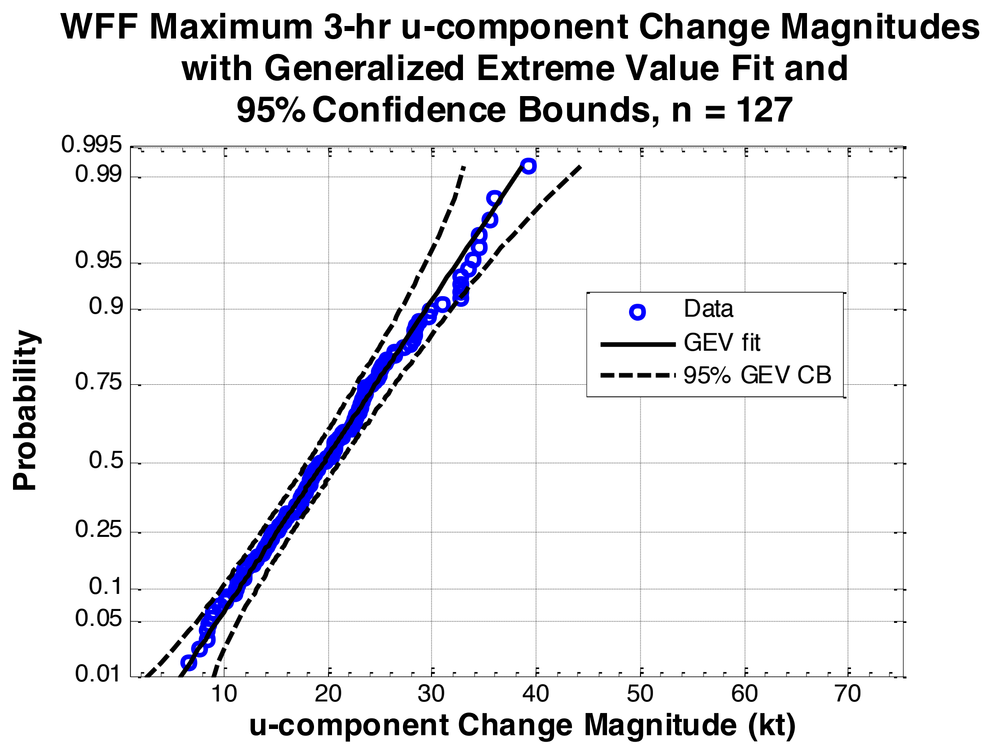


Figure 13. WFF maximum wind change from the 2-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 75.



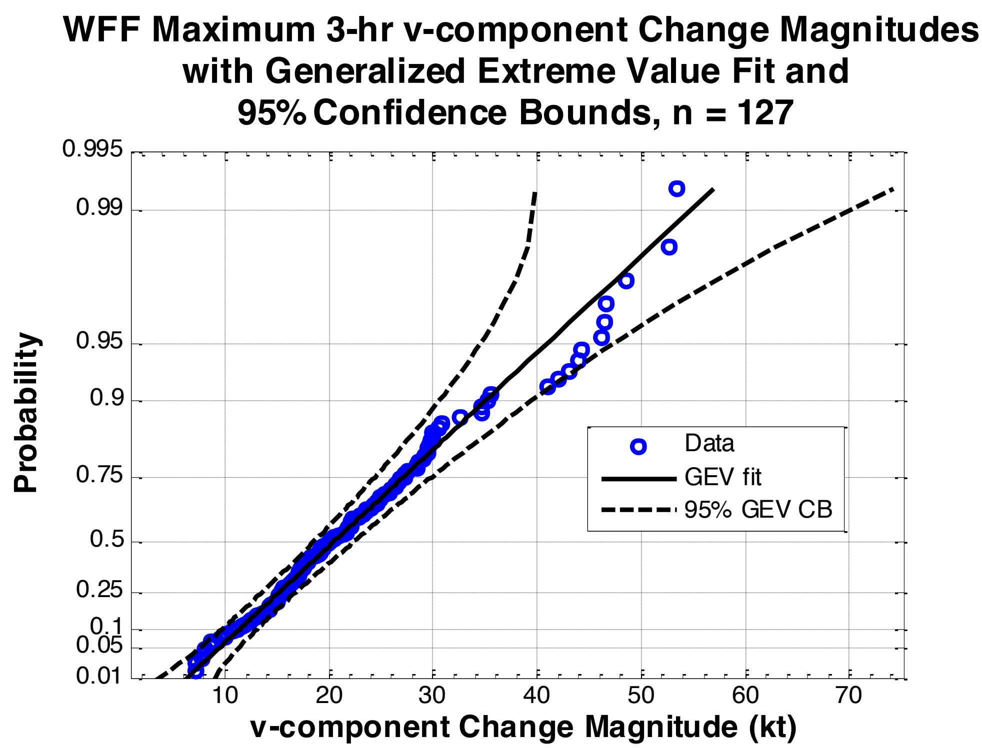
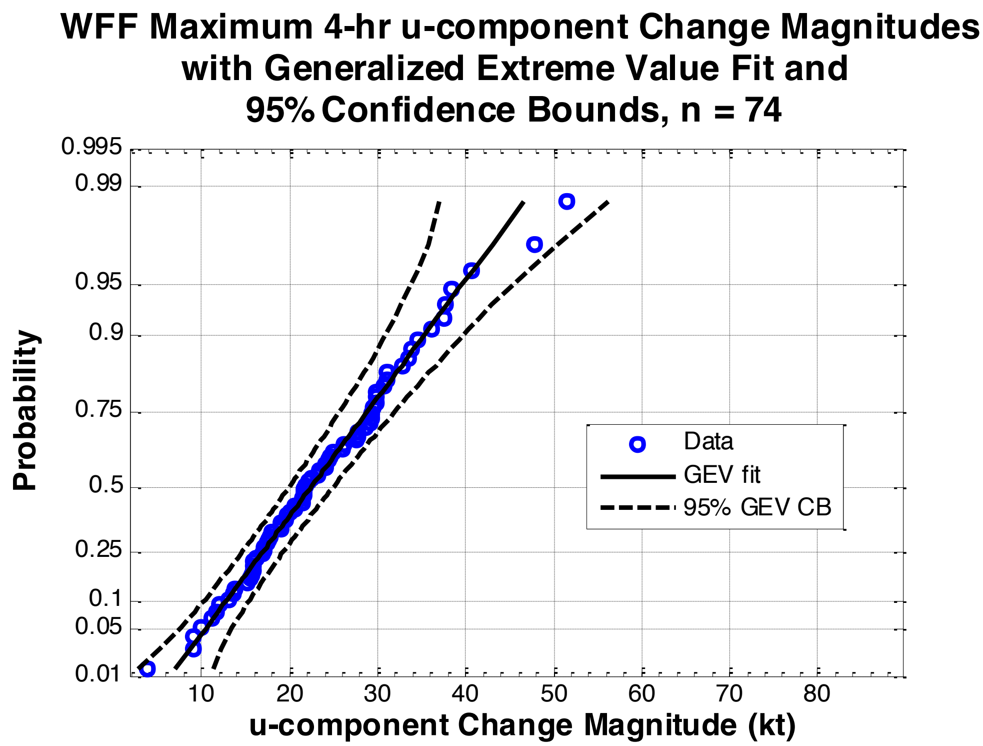


Figure 14. WFF maximum wind change from the 3-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 54.



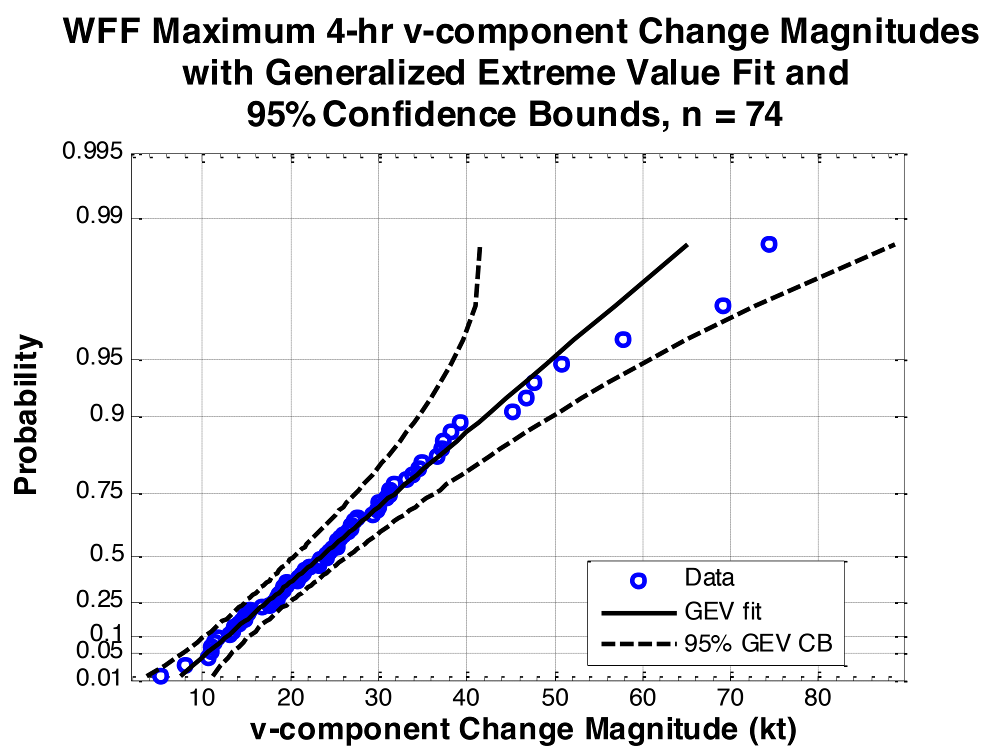


Figure 15. WFF maximum wind change from the 4-hour wind pairs with 95% CB for the U-(top) and V-component (bottom) wind changes. The magnitude of the wind component change is on the x-axis and probability is on the y-axis. The number (n) of pairs in the analysis is 74.

5. Conclusion

Temporal UL wind pair databases were generated for NASA's LSP to incorporate into commit-to-launch decisions based on UL wind assessments. Databases for five time intervals (0.75, 1.5, 2-,3- and 4 hours) at the USAF ER and WR, as well as NASA's WFF were generated through use of historical data at each location. Multiple sources that measure UL atmospheric winds at the requested sites were used for this task. Databases were compiled using wind profiles from rawinsonde, Jimsphere, and DRWP systems. Extensive QC checks were applied on the data to remove unacceptable profiles. Statistical analyses of the resultant wind pairs from each site were performed to determine if the observed extreme wind changes in the sample pairs represent extreme temporal wind change. The resultant ER wind pair databases yielded sample sizes that characterize the extreme wind change environment and no restrictions on the usage exist. The WR wind pair database sample size is large enough for vehicle performance assessments up to the 99th percentile level. However, due to the small sample size for each wind pair time period at WFF, low confidence exists that the observed extremes in each time period characterizes the extreme wind change environment. Therefore, for any vehicle performance applications at WFF, the recommendation is to apply the extreme 4-hour wind change values for all time change intervals of interest.

6. Future Work

Future work on this task would include increasing the number of WR wind pairs by adding data from the WR DRWP systems into the WR temporal wind pair databases. This process would include, at the minimum, QC of the individual 50-MHz and 915-MHz wind profiles. Acceptable wind profiles from each DRWP system would be spliced to generate vertically complete wind profiles and available pairs would then be incorporated into the existing databases.

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